Teaching design simulation

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Keywords

Design analysis, simulation, CFD, airflow

Abstract

The democratization of information and communication technologies (ICT) has promoted integration of computing in the design studio and of design activities in the CAAD courses. In addition it has also shifted the focus of CAAD courses from technical skills and general theoretical issues to current, specific design issues, such as the relationship between geometric modeling and construction, design communication and design analysis. CAAD courses (especially advanced ones) increasingly attempt to introduce these issues and corresponding advanced ICT in a design context that outlines the possibilities of these technologies and the underlying computational design methodology and bring research closer to teaching. One such issue is design analysis, especially in the early design stages when many fundamental decisions are taken on the basis of incomplete and insecure information. Simulation provides the computational means for projecting building behaviour and performance. The paper describes the application of a specific simulation technique, computational fluid dynamics (CFD), for the analysis of airflow in and around buildings in the context of an advanced CAAD course. In this course students are required to design a multifunctional exposition building. Even though students are unfamiliar with the particular CFD system, as well as with part of the simulation subject matter, they are able to produce descriptions of their designs with effectiveness and efficiency.

Introduction: design analysis

In the past decade the computer has been rapidly transformed from an instrument of a scientific elite to a general-purpose, relatively affordable and widely available tool for an increasing number of applications. The democratization of ICT in architectural practice has promoted a wider spectrum for computing applications in architectural education. The necessity of computer skills in practice means that the use of computer modeling and visualization tools alongside analog media is becoming commonplace. Advanced CAAD courses increasingly attempt to introduce these issues and corresponding advanced ICT in a design framework that outlines the possibilities of these technologies and the underlying computational design methodology. This framework is essential for bringing research as well as practice closer to teaching.

Probably the most promising issue in this framework is design analysis. The main consequence of using analysis is the abandonment of prescriptive or proscriptive approaches, where a design is evaluated on the basis of known features, in favor of the *descriptive* approach. In this approach, the intuitive preferences of the designer are not supplanted by arbitrary formal systems but supported and complemented with measurable information on the design's projected behavior and performance . For the early design stages, this information is extracted from the available design representations and external corpora. In this context, CFD simulation provides the computational means for projecting building behavior and performance. By presenting these projections in the manner of scientific visualization, i.e. by means of coupled visual and analytical representations, we provide the designer with a consistent flow of design information that forms the subject matter or background of subsequent design decisions.

CFD

Computational Fluid Dynamics (CFD) is a technique for calculating patterns of fluid flow. CFD makes use of a fundamental set of partial differential equations that describe the essence of the fluid flow. These equations derive from three basic principles: conservation of mass, conservation of momentum and conservation of energy within that fluid. Since the equations are far too complex to be solved analytically, iteration is used to arrive at a solution that describes the characteristics of the moving fluid with specific numbers for velocities, temperatures and pressures, among others. Fast computers are used to solve the equations thousands of times while each step makes the solution more accurate (Anderson 1995).

The production of healthy buildings presupposes monitoring and control of several qualities of indoor climate in the design process. Of huge importance for the indoor climate are the temperature and air velocities that occur in spaces where occupants reside. The indoor climate of a building is a result of active conditions such as sun and occupant activity and passive building features such a window area and shape, natural shading and material properties. In optimal cases, the passive building features are configured in a manner which results in comfortable indoor climate with temperatures, air velocities and air purity within prescribed ranges. More often than not however, climate parameters exceed ranges that are considered healthy and additional cooling, heating or ventilation is needed. In these cases, building services are needed to control the indoor climate effectively. Installation components like boilers, radiators, fans and air inlets are installed on strategic positions in the design.

However, in building design the transport of heat, air and water through a building are among the processes that are most difficult to predict and depict. These transports have the characteristic of being highly variable. In most cases, the problems designers need to solve change over time. When certain elements are brought in to control processes such as air transport, new problems arise, whereby problems and solutions interact. This interaction makes it difficult to predict building features such as indoor climate or heat transport. Even experts find it hard to judge design situations that are different every time and where small variations can have large effects.

With the rise of the computer, many experts recognized the computer's potential to solve the highly complex problems with increased speed and accuracy. CFD tools can provide designers with projections of all indoor climate parameters at any point in time of day or location in the building. Moreover, it can simulate dynamic phenomena such as temperature oscillations and turbulence that are of interest to specialists.

A CFD exercise

Advanced design computing courses, where students have sufficient understanding of geometric modeling, as well as of the complexity of the digital design process, offer interesting possibilities for integrating CFD simulation in architectural design education. At the Faculty of Architecture, Delft University of Technology, this takes place in the D7 design computing course, in the form of a semi-independent CFD exercise.

Initially, students are asked to select an enclosed space from their designs where information on airflow would be interesting. Areas where people reside for a considerable length of time are particularly relevant. The spaces should be connected with the outside environment only by means of doors and windows. In the event that designs do not have a separated space, the airflow around the building can be analyzed instead. Since the design assignment of the course deals with an exhibition building, most students choose the main exhibition space as their subject for CFD analysis.

In order to analyze the airflow within buildings effectively, the ventilation context of the space should be defined in advance. This means identifying the location and characteristics of the air in- and outlets, as well as any pollution sources that exist within the space. In order to aid the students with this task, a quick reference scheme was developed. This scheme organizes the options for ventilation principles and offers simple formulae to determine ventilation characteristics. Consulting the scheme only takes a couple of minutes and is supervised by an indoor climate specialist. The aim of this step is to make students aware of the indoor climate of their designs and to provide a framework within which the simulations can be held.

A prerequisite to the simulation is a representation of the design in the CAD tools used within the course. Students represent their designs using a few simple rules to give the representation structure. One of those rules is to draw the boundaries of the spaces using closed, extruded polylines. Elements such as doors, windows and air inlets are also drawn using polylines and are placed on corresponding layers. This basic representation largely corresponds with the design representation used for most of the course.

Producing the CFD representation essentially amounts to copying the design elements that are relevant to airflow simulation. The ventilation concepts of the previous step can also be drawn in the representation using a component library. After all design information has been collected it can be prepared for simulation. Since specialists guide this process, most simulations run without trouble. However, in some cases a slight adaptation of the simulation input is required.

After the initial simulation, the results are presented using three-dimensional visualization. The airflow is illustrated by introducing small particles in the air and tracing their path. The particle tracing method can be combined with the use of color to represent air speed or temperature. These kinds of visualizations are useful to focus the attention on medium size local phenomena such as draft or ventilation inefficiencies. By analyzing and evaluating the initial simulation results, students identify possible indoor climate problems such as the high air velocities. Subsequent design variants improve on the weak points identified in the first simulation. Simulating several design options with varying window sizes or inlet velocities can uncover optimal configurations where drafts are avoided or ventilation efficiency is improved.

The visualization of simulation results using particles facilitates recognition of building aspects that have a large influence on the indoor climate. Students are asked to evaluate the simulation results they produced with help from the indoor climate specialist. The designs are analyzed and strong and weak points that can account for the simulation results are identified. Subsequently students revise their designs, taking in account the findings from the simulation.

The final part of the exercise is presentation of results and findings in the Internet pages students maintain for all their activities throughout the entire course. They are asked to include a representation of the original design and the main design goals with respect to indoor climate and airflow. A second representation should indicate which indoor climate elements are brought into the design. In most cases, abstractions in shape are needed to adapt the geometry of the design to the requirements for CFD simulation. Also shown are the design configurations that are input into the CFD application, as well as the results produced by simulation. These are accompanied by an account of indoor climate problems and causes. Lastly, a representation and a review of the revised design are given, also with respect to related design aspects.

Discussion

A building scale at which consequences of design actions are quite noticeable is the large space. Large spaces frequently accommodate a single activity such as an auditorium or sports center. Spaces such as exhibition spaces or open-plan offices contain separated or semi-separated activities. CFD analysis proves powerful enough to predict large air circulation patterns that cause annoying drafts and the means for studying and improving the design of installations.

The exercise is generally a positive experience for both students and teachers. For most students the exercise sparks an interest in indoor climate. The ability of having feedback on indoor climate stimulates curiosity and exploration (as opposed to blind obedience to rules-of-thumb). At the same time, the possibility to analyze and control indoor environmental effects increases confidence in the chosen design strategies and ideas. However, in the framework of a single design computing course there is insufficient time for the analysis of a reasonable number of designs at different stages of development. This obviously discourages use of CFD simulation, especially as most students have few experiences with indoor climate analysis and simulation.

Our research into the applicability of CFD simulation to building design and analysis now attempts to improve the effectiveness of the use of simulation. We feel that collections of design knowledge in the form of case bases will facilitate definition of possible solution types and spaces as well as provide additional input to the analysis and simulation of building designs.

The use of CFD in teaching has reinforced our belief in the necessity such improvement of the basic design instrumentation. New ICT such as simulation presuppose a comprehensive and consistent conceptual infrastructure, capable of accommodating new media and methods without loss of direction and effectiveness in the main pursue of the architect, the creation of appropriate built space.

References

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